A method implemented, e.g., as software and a device operating according to the method for the automatic evaluation and analysis of a capnogram are provided. Measured values for an expired volume—volume measured values—and measured values for a carbon dioxide concentration—concentration measured values—are recorded for the breathing gas of a test subject. An automatic approximation of at least one part of the curve of the concentration measured values over the volume measured values is performed, by using three mutually adjacent straight lines for the approximation. The area is determined using the third straight line according to Fowler for the determination of the serial dead space $V_d$. 

![Graph showing FC02 vs V]
Fig. 2
Fig. 6
METHOD AND DEVICE FOR THE
AUTOMATIC EVALUATION AND ANALYSIS
OF A CAPNOMETRIC AND COMPUTER
PROGRAM FOR IMPLEMENTING THE
METHOD AS WELL AS COMPUTER
PROGRAM PRODUCT WITH SUCH A
COMPUTER PROGRAM
CROSS REFERENCE TO RELATED
APPLICATIONS

[0001] This application claims the benefit of priority under
047 546.7 filed Oct. 5, 2010, the entire contents of which are
incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention pertains to a method for the
automatic evaluation and/or analysis of a so-called capno-
gram, especially a volume capnogram, as well as to a cor-
responding device, which is provided and suitable for automati-
cally carrying out the method. Any device in which the
investigation of respiration or of the lung function of a test
subject or patient plays a role, i.e., for example, an anesthesia
apparatus or a respirator, may be considered for use as such a
device. While a respirator partly or temporarily assists the
breathing of a test subject or patient, hereinafter globally
called test subject, other devices, e.g., capnometers, are
intended essentially, without such an active function, essen-
tially for analytical purposes, e.g., for non-invasive methods
for supporting a diagnosis especially of pathological changes
of the lungs or for the observation of therapeutic results in the
treatment of the lungs, etc. All devices of the above-men-
tioned type will be summed up here and below under the term
device or apparatus. Implementation as software is consid-
ered for the method, so that the present invention also pertains
to a corresponding computer program and to a computer
program product with such a computer program.

BACKGROUND OF THE INVENTION

[0003] Representation of a so-called volume capnogram is
common in prior art respirators to enable the caregivers to
assess the breathing process, for example, in case of such a
device used in intensive care.

[0004] FIG. 1 shows such a volume capnogram as an
example.

[0005] To obtain such a volume capnogram, measured val-
ues for an indicator of an expired volume and measured
values for an indicator of a carbon dioxide concentra-
tion—CO₂ concentration for short—are recorded for the breathing
gas of a test subject. For example, a quantity of air flow that
can be measured with a flow sensor may be used as an indi-
cator of an expired volume. For example, the actual CO₂
concentration (FCO₂) itself or a CO₂ partial pressure (PCO₂)
may be used as the indicator of a CO₂ concentration. A CO₂
sensor may be used to measure the CO₂ concentration. The
measured values are usually recorded at preset or presettable,
normally non-uniform points in time, so that a plurality of value
pairs are obtained.

[0006] Two measured values each, recorded at the same
time or at least essentially at the same time, form a value pair.
The recorded measured values are measured values for an
indicator of a carbon dioxide concentration, heretofore
called concentration measured values for short, and measured
values for an indicator of the expired volume, hereinafter
correspondingly called volume measured values for short.
Each value pair correspondingly comprises a concentra-
tion measured value and a volume measured value. A linear curve
is obtained by the graphic representation of the measured
values recorded during an expiration process in a Cartesian
system of coordinates, namely, when representing the con-
centration measured values over the corresponding volume
measured values, and the entirety of the measured values thus
represented forms the volume capnogram. The volume mea-
sured values are plotted on the abscissa and the concentration
measured values on the ordinate.

[0007] The volume capnogram recognizes has three sec-
tions, which are called phase 1, phase 2 and phase 3, begin-
going from the left, in the scientific literature, and are designat-
ed by P1, P2 and P3 in FIG. 1.

[0008] At the beginning of expiration, breathing gas (gas),
which has not participated in the gas exchange with the blood,
reaches from the airways the respective sensor, e.g., the CO₂
sensor. It correspondingly contains only a small percentage of
or no CO₂ (phase 1). The measurable CO₂ concentration
increases appreciably (phase 2) only when gas from the
alveoli of the lungs reaches the CO₂ sensor. The CO₂
concentration reaches a plateau at the end of the rise phase, and
the CO₂ concentration normally continues to rise at least slightly
even within the plateau (phase 3).

[0009] Two parameters are of special significance in the
evaluation of the capnogram: On the one hand, the volume
beginning from which the CO₂ concentration rises and, on the
other hand, the change in the CO₂ concentration in the area of
the plateau.

[0010] The volume beginning from which the CO₂ con-
centration rises describes the expired quantity of gas, which has
not reached the alveoli and could not therefore participate in
the gas exchange with the blood. At least the gas content in the
mouth, pharynx and upper part of the trachea of the test
subject belongs to this quantity of gas. There is no gas
exchange in this tidal volume area via the alveoli. The CO₂
concentration will consequently correspond essentially to the
CO₂ concentration in the air inspired previously. This volume
is called a serial dead space or, after subtracting the gas
volume of the measuring device, also anatomic dead space. It
is designated by the symbol VDs in the literature. The dead
space or a change in the dead space during a therapy or during
a longer-lasting observation of a test subject can be used as an
indication of changes in the lungs or airways.

[0011] The change in the CO₂ concentration in the area of
the plateau is quite generally an indicator of the quality of the
gas exchange in the lungs.

[0012] The method according to Fowler (Fowler W. S.,
Lung function studies II: The respiratory dead space, Am. J.
Physiol., Vol. 154 (1948), pp. 405-416) has come commonly
to use and is frequently used for the determination of these
two parameters.

[0013] The measured value curve in FIG. 1 is also called
FCO₂ curve for the further explanation, because the measured
value curve represents the carbon dioxide concentration
(PCO₂) during the expiration process, i.e., over the volume
measured values. Fowler's method begins by drawing a
straight line through the plateau of the FCO₂ curve in phase 3
"with the naked eye." A vertical line is subsequently posi-
tioned in the course of the FCO₂ curve in phase 2. The posi-
tion of the vertical line is selected to be such that an area to
the left of the vertical line and an area to the right of the vertical
line are equal or at least approximately equal. The area being considered here to the right of the vertical line is defined, on the one hand, by the line itself, then the FCO\textsubscript{2} curve and finally the straight line drawn through the plateau. The area to the left of the vertical line is likewise defined by the line itself and the FCO\textsubscript{2} curve as well as the abscissa of the system of coordinates (FCO\textsubscript{2}, zero line). FIG. 2 shows this fact graphically. The two areas to the left and right of the vertical line are designated by A1 and A2, respectively, in the diagram. Such an evaluation has been performed so far only by medical staff trained in this field based on an examination of the capnogram, and the position of the vertical line was essentially estimated in light of the equality of the areas adjoining on the right and left. An actual determination of the contents of the two areas adjoining on the right and left and hence an exact positioning of the vertical line to determine the serial dead space has been performed essentially for scientific publications and the like.

[0014] An automatic evaluation of a volume capnogram, called an expirinogram here, has become known from DE 10 2004 039 194 A1. Reference is made to this document to avoid repetitions that are unneeded here, e.g., in respect to the explanation of some technical terms such as “dead space” or generally in respect to the explanation of the physiological principles of gas exchange in the lungs.

[0015] The approach from DE 10 2004 039 194 A uses a certain type of function, which comes close to an ideal capnogram. Such an approach is not flexible enough to identify capnograms that considerably differ therefrom and are hence unusable without human interaction.

**SUMMARY OF THE INVENTION**

[0016] The object of the present invention is to provide a sufficiently flexible method for the automatic evaluation of a volume capnogram, which both determines the straight line to be provided for the Fowler algorithm through phase 3 and is capable of identifying usable capnograms.

[0017] This object is accomplished according to the present invention with a method with the following method steps provided for this in a method for automatically evaluating and analyzing a capnogram, e.g., in a method for operating a respirator or generally in a method for operating a device for the analysis of breathing and/or the lung function: Measured values for an indicator of an expired volume and measured values for an indicator of a carbon dioxide concentration are recorded for the breathing gas of a test subject. The measured values for an indicator of the carbon dioxide concentration and the measured values for an indicator of the expired volume are called here and hereinafter concentration measured values and volume measured values for short. A curve of the concentration measured values over the volume measured values forms a basis for an automatic analysis of the measured values recorded with the following additional steps: An automatic approximation of the curve of the concentration measured values over the volume measured values is performed by means of three sections of the straight line.

[0018] A computer-implemented, numerical optimization algorithm, e.g., the Levenberg-Marquardt algorithm, which is known to be a numerical optimization algorithm for solving nonlinear compensation problems by means of the least squares method, may be used for the automatic approximation of at least part of the curve describing the concentration measured values over the volume measured values. The least squares method is known per se as a standard mathematical method for compensation calculation and is used in the Levenberg-Marquardt algorithm to evaluate the progression of optimization. In general, a curve, which extends as close as possible to the points of the point set, is sought for a point set preset by measured values. The point set preset by measured values in the problem being considered here is represented by the individual points of the capnogram, and the approximation is performed such that six parameters are determined, comprising an initial concentration value F0, a first and second value pairs (V1, F1), (V2, F2), and a final concentration value F3. Together with the fixed initial and final volume values V0 and V3, these parameters define three straight lines, which adjoin each other and by means of which the capnogram is approximated, the first value pair defining the end point of the first section and the starting point of the second section and the second value pair defining the end point of the second section and the starting point of the third section.

[0019] Based on the parameters determined, an indicator for the serial dead space of the lungs of the test subject is determined corresponding to Fowler’s method as an automatic analysis of the recorded measured values.

[0020] The above-mentioned object is also accomplished with a device for carrying out the method. A respirator or any other apparatus, which assists respiration or is intended for breathing analysis or the like, especially a capnometer, may be used as a device. The device may also be comprised as an essentially separate functional unit of an apparatus having further functions. A respirator may in turn be used as such an apparatus comprising the device as a functional unit.

[0021] The advantage of the present invention is that the underlying approach makes possible a simple implementation of the above-described method and possibly also embodiments thereof, which will be explained below. This analogously also applies to the creation of a device or apparatus, which device or apparatus carries out the method, operates according to the method or is intended for carrying out the method.

[0022] Advantageous embodiments of the present invention are provided.

[0023] The indicator of the serial dead space of the lungs of the test subject can be automatically estimated in an especially simple manner on the basis of a distance between the volume measured values belonging to the first and second value pairs, e.g., by taking the mean of the two volume measured values as an indicator of the serial dead space. If the volume measured values of the first and second value pairs are designated symbolically by V1 and V2, respectively, a numerical value is obtained as an indicator of the serial dead space—symbol VDs—in the form of

\[
V_{\text{Ds}} = \frac{(V^1 - F1) + (V^2 - F2)}{2} = \frac{(V^1 + V^2)}{2}.
\]

The automatically determined indicator of the serial dead space of the lungs of the test subject can be automatically improved iteratively according to Fowler. The value determined at first for the serial dead space and then the value determined newly stepwise for the serial dead space are shifted for this to the right or left in the system of coordinates until a first area and a second area before and after the determined value agree. The first and second area being considered here before and after the determined value are the areas also considered in Fowler’s method and reference is therefore made to their representation in FIG. 2. The iterative improvement begins with a value located, e.g., in the middle between the two volume measured values belonging to the first and
second value pairs as an initial indicator of the serial dead space. The contents of the two areas A1 and A2 are determined for this value. We then advance in the direction of the larger area measured point by measured point and the area contents are determined anew. The small area is now enlarged and the larger area reduced. The procedure stops when the measured point at which the smaller area becomes the larger one is reached. The area between this and the preceding measured point can finally be divided into A1 and A2 by interpolation, so that equality is achieved. The volume thus determined is the sought value Vds.

[0024] Based on the second value pair and another, last value pair, with a final volume measured value and a corresponding concentration measured value, an indicator can be determined for the quality of a gas exchange in the lungs of the test subject. It is known that the increase in the concentration measured values in the area of the plateau in phase 3 of the capnogram is an indicator of the quality of gas exchange in the lungs. The increase in the concentration measured values in the area of the plateau in phase 3 can be expressed as follows with the second value pair and last value pair and the volume and respective concentration measured values comprised thereby, here and hereinafter symbolically designated by V2 and F2 as well as V3 and F3:

\[ dFCO_2/dV = (F3-F2)/(V3-V2). \]

An estimation of the quality of the approximation and/or an estimation of the usability of the measured values recorded can be automatically performed on the basis of the first and second value pairs and the last value pair. For example, the fact that an actual value is below a preset or presettable threshold value for a difference of the final volume measured value V3 and the volume measured value V2 belonging to the second value pair can be automatically evaluated as lack of usability of the measured values. Such an evaluation can relate, as in the preceding example, to the second and last value pairs only. On the other hand, the evaluation may also relate to the first and second value pairs or to the second value pair and the last value pair by comparing, e.g., the slopes of the straight lines extending between them, i.e., of the straight lines in phase 2 and phase 3 of the capnogram. Permissible relations are defined and suitably made available for such a comparison, i.e., stored, e.g., in a memory, and the automatic evaluation as a lack of quality of the approximation or lack of usability of the measured value can be made contingent upon whether the range of permissible relations thus defined is abandoned. Further criteria can be derived from a comparison of the length of phase 3 with values for, e.g., V3 or Vds, etc.

[0025] An exemplary embodiment of the present invention will be explained below on the basis of the drawings. Objects or elements corresponding to each other are designated by the same reference numbers in all figures.

[0026] The exemplary embodiment shall not be construed to represent a limitation of the present invention. Variations and modifications are rather possible within the framework of the present disclosure, which the person skilled in the art can find, for example, by combining or modifying individual features or process steps that are described in conjunction with the general or special specification part and are contained in the claims and/or drawings for accomplishing the object and which can lead to a new object or to new process steps or sequences of process steps by means of features that can be combined. The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and specific objects attained by its uses, reference is made to the accompanying drawings and descriptive matter in which preferred embodiments of the invention are illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] In the drawings:

[0028] FIG. 1 is a graph showing a so-called volume capnogram, i.e., a curve of measured values here, which represent a CO2 concentration in the expired breathing air, over measured values for the expired gas volume;

[0029] FIG. 2 is a graph showing the capnogram from FIG. 1 with two straight lines fitted into same for evaluating the capnogram according to Fowler’s method;

[0030] FIG. 3 is a schematically simplified view of a device for the automatic evaluation and analysis of a capnogram;

[0031] FIG. 4 is a simplified flow chart of a control program, under the control of which the automatic evaluation and analysis of a capnogram is carried out;

[0032] FIG. 5 is a simplified view of a result of an automatic evaluation and analysis of a capnogram; and

[0033] FIG. 6 is a simplified view of an automatic improvement of the result after a first evaluation and analysis step as shown in FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] Referring to the drawings in particular, FIG. 1 shows, as was mentioned already, a curve of measured values, which represent a CO2 concentration in the expired breathing air, over measured values for the expired gas volume. The representation of the measured values, as is shown in FIG. 1, is called a volume capnogram. The measured values for the CO2 concentration—concentration measured values (e.g., symbolically designated by \( F_{r1}, F_{r2}, \ldots, F_{rN} \), wherein \( k \) to \( k+n \) are scanning times for recording the measured values) are plotted in the Cartesian system of coordinates shown as FCO2 along the ordinate. The measured values for the expired gas volume—volume measured values (e.g., analogously to the above at the concentration measured values, symbolically designated by \( V_{r1}, V_{r2}, \ldots, V_{rN} \),—are plotted as V along the abscissa. The curve describing the measured values is called the FCO2 curve, and three sections or phases P1, P2, P3 are recognizable in this. Important parameters of the FCO2 curve are an indicator of the serial dead space, symbolically designated as Vds, approximately in the middle of the second phase P2 and a slope dFCO2/dV of the third phase P3.

[0035] FIG. 2 shows, as was also mentioned already, the approach for determining the above-mentioned parameters with Fowler’s method (Fowler W. S., Lung function studies II: The respiratory dead space, Am. J. Physiol., Vol. 154 (1948), pp. 405-416). A first straight line is fitted for this to the FCO2 curve in the area of the third phase 3 and a vertical line is subsequently drawn into the area of the second phase P2 such that the contents of the areas A1, A2 defined to the right and left by the vertical line and the FCO2 line are equal or at least essentially equal.

[0036] FIG. 3 schematically shows in a simplified form a device 10 for the automatic determination of at least one of the above-mentioned two parameters. A respirator or an apparatus of the above-described type may be used as the device 10. Such an apparatus or a respirator may also comprise the
device 10 as a functional unit. A modular design of the device 10 may also be considered in the latter case, so that the device can be combined with existing apparatuses in order to expand the range of functions thereof.

[0037] Breathing air expired by a test subject 14 flows into a line unit 12, which is comprised either by the device 10 or an apparatus comprising the device 10. If the device 10 is used in a respirator, the test subject 14 is supplied, depending on the embodiment of the respirator, via the line unit 12 with a breathing gas enriched especially with oxygen. The gas expired by the test subject 14 reaches, at any rate, a first sensor for detecting volume measured values, e.g., a flow sensor 16, which measures the volume flow (flow), and a second sensor for detecting concentration measured values, e.g., a CO₂ sensor 18, which measures the CO₂ concentration or CO₂ partial pressure. The order in which the sensors 16, 18 are arranged is freely selectable and the concentration measured values can be equally recorded in the line unit 12 before the volume measured value or at about the same site in the line unit 12. Both sensors 16, 18 send the respective measured values recorded to an analysis unit 20 of device 10. Sensors 16, 18 may be part of the device 10 or part of an apparatus comprising the device 10. In the latter case, the device comprises means, i.e., for example, an interface, for taking over the measured values from the sensors 16, 18. At least one memory 22 and a processing unit 24 in the manner of a microprocessor or the like belong to the device 10. Measured values entered from the sensors 16, 18 are stored in a data storage area 26 of memory 22. The function of the analysis unit 20 is determined by a computer program stored in a program memory area 28 of the memory 22, which is called a control program 30 here. The reception and storage of the volume and concentration measured values sent by the sensors 16, 18 in the data storage area 26 take place under the control of the control program 30. Furthermore, evaluation and analysis of the measured values thus stored take place under the control of the control program 30. As a result of the evaluation/analysis, at least one indicator of the serial dead space of the lungs of the test subject 14 is shown on a display unit, e.g., an optical display device in the manner of a display screen 32. As an alternative or in addition, an indicator of the quality of the gas exchange in the lungs of the test subject 14 is displayed. The values displayed or possibly displayed are the values determined for Vds and dFCO₂/dV. The display unit may be part of the device 10 or of the apparatus comprising said device or may be arranged externally from same or arranged at said device or apparatus and connected to said device or apparatus in a communicating manner.

[0039] FIG. 4 graphically shows individual aspects of the control program 30 (FIG. 3) on the basis of a flow chart.

and end of an expiration process are known per se. The reversal of the sign of the volume measured values is mentioned here only as an example. The first program code block is executed until all the measured values belonging to an expiration process are received and stored in the data storage area 26 of memory 22 of the analysis unit 20.

[0040] The analysis of the measured values received is then performed. A second program code block 36 is provided herefor. This comprises, e.g., a computer-implemented Lev-enberg-Marquardt algorithm, which is known per se. The algorithm is provided to determine three straight lines, which describe the curve of the concentration measured values recorded over the volume measured value recorded, i.e., the FCO₂ curve, as accurately as possible.

[0041] Based on Fowler's method, it would be possible to begin at first by determining a straight line, which describes the pattern of the plateau in the third phase P3 of the capno gram or of the FCO₂ curve as accurately as possible. Volume measured values, which describe the starting point and end point of such a straight line, must be determined for this. The volume measured value (final volume) belonging to the end point of the straight line is set with the last value recorded for the expiration process. However, a volume measured value (initial volume) that can be considered for a starting point of the straight line, is, as it were, in the middle of the diagram and is not set at first in any way.

[0042] Provisions are therefore made for the automatic approximation of at least part of the curve of the concentration measured values over the volume measured value to determine three straight lines, which follow each other and describe the curve of the measured values as accurately as possible. The formulation in which one or more straight lines are fitted to the measured values or the FCO₂ curve will also be described below as an alternative for the formulation of the most accurate description possible of the measured values or FCO₂ curve or a part thereof by one or more straight lines. When the term FCO₂ curve is used here and hereinafter, it means any set of measured values that go back to an indicator of the carbon dioxide concentration, i.e., for example, also a curve that does not go back directly to a measured carbon dioxide concentration but to measured values for a carbon dioxide partial pressure.

[0043] In general, a straight line can be expressed, as is known, in the Cartesian system of coordinates by a linear equation, whose general form is

\[ y = mx + b \]

in which \( n \) is the slope of the straight line and \( m \) is the y axis intercept of the straight line, i.e., the point at which the straight line intersects the ordinate of the system of coordinates.

[0044] A straight line with the linear equation shown above is defined by all points x,y.

[0045] Three straight lines, which adjoin each other but are separate each in itself, are to be fitted to the FCO₂ curve in this situation, so that a limited range of validity is thus obtained. Each of the straight lines being sought shall be defined only for the first segment, second segment or third phase P1, P2, P3 of the FCO₂ curve. The values V0 and V1 are correspondingly set as starting and end volume values of the first straight line for the first phase P1, the values V1 and V2 are set as initial and end volume values of the second straight line for the second phase P2, and the values V2 and V3 are set as initial and end volume values of the third straight line for the third phase. At least the
volume values V1 and V2 are now to be determined by a suitable automatic determination.

[0046] The corresponding functional equations of the three straight lines are:

- Straight line for the first phase P1 (first straight line) with a range of validity of V = V0 .. V1:
  \[ FC02 = F0(V - V0) + F1(V0 + F0) \]
- Straight line for the second phase P2 (second straight line) with a range of validity of V = V1 .. V2:
  \[ FC02 = F1(V - V1) + F2(V1 + F1) \]
- Straight line for the third phase P3 (third straight line) with a range of validity of V = V2 .. V3:
  \[ FC02 = F2(V - V2) + F3(V2 + F2) \]

The parameters F0, F1, F2, F3, V1, and V2 of the three linear equations must be determined such that the best possible approximation of the three straight lines to the FC02 curve is obtained corresponding to the measured values recorded. An optimization algorithm of the type of the Levenberg-Marquardt algorithm (Marquardt, D. W.: Journal of the Society for Industrial and Applied Mathematics, 11(1963), pp. 431-441) is suitable for this. Improvement of the respective values found for the parameters to be determined, here F0, F1, F2, F3, V1, and V2 is successively performed with the respective optimization algorithm, and an evaluation of the quality of the respective parameters found is performed on the basis of the sum of squares of the deviation of the straight line defined by the parameters from the measured value curve to be approximated. The goal is a minimal deviation, e.g., minimization of the respective sum of squares obtained.

[0047] FIG. 5 shows the result of a fitting of three straight lines, namely, of a first straight line 38 in the first phase P1; of a second straight line 40 in the second phase P2 and of a third straight line 42 in the third phase P3 to the FC02 curve shown already in FIG. 2. The parameters are checked to determine whether they have meaningful relations to one another; if not, the evaluation of the capnogram is discarded.

[0048] The second value pair 46 defines an end point of the second straight line and a starting point of the third straight line 42, i.e., of the third approximated section. Based on the first and second value pair 44, 46, a first estimated value can be determined according to Fowler for the serial dead space of the lungs of the test subject 14, e.g., as Vd = (V2 + V1)/2. The corresponding areas A1 and A2 are determined by numerical integration. Vds is then varied such that A1 becomes equal to A2. A third program code block 50 (FIG. 4) is provided for this evaluation of the measured values recorded subsequent to the analysis of these measured values.

[0049] An indicator of the quality of a gas exchange in the lungs of the test subject 14 can be determined, e.g., as dFCO2/dV = (F3 - F2) / (V3 - V2), on the basis of the second value pair 46 with the volume measured value V2 and the concentration measured value F2 and of another, last value pair 48, with an end volume measured value V3 and a corresponding concentration measured value F3. A fourth program code block 52 (FIG. 4) is provided for this optional evaluation. The functionality of the third and fourth program code blocks 50, 52 may also be combined.

[0050] Finally, FIG. 6 shows a possibility of improving the approximation of the third straight line 42. As can be recognized from FIG. 5, the third straight line 42 intersects the measured value curve close to point V2. This intersection is symbolically designated by VX in FIG. 6. The third straight line 42 can now be approximated anew by taking into account only the volume measured values and corresponding concentration measured values above the intersection VX. The influence of the inflection point in the measured value curve at V2, which leads to lower values, is now eliminated.

[0051] As a partial functionality of the third and/or fourth program code block 50, 52 of the control program 30 (FIG. 4) or in the form of a separate program code block (not shown), the control program 30 comprises program code instructions for actuating the display unit, i.e., e.g., the display screen 32, in order to output the values determined for Vds and/or dFCO2/dV.

[0052] The part of the control program 30 shown in FIG. 4 with the first, second, third and fourth program code blocks 34, 36, 50, 52 can be run once, continuously or with a preset or presettable number of repetitions, and interruption by a user is possible in case of a continuous or multiply repeated run. This is represented by the case discrimination block 64, which concludes the structured program in the view in FIG. 4.

[0053] Some aspects of the above explanations can be briefly summarized as follows: A method and a device operating according to the method for the automatic evaluation and analysis of a capnogram are provided, wherein measured values for an indicator of an expired volume and measured values for an indicator of a carbon dioxide concentration are recorded for the breathing gas of a test subject 14, wherein the measured values for an indicator of the carbon dioxide concentration—concentration measured values—over the measured values for an indicator of the expired volume—volume measured values—form a basis for an automatic analysis of the measured values recorded, wherein an automatic approximation of at least part of the curve of the concentration measured values over the volume measured values is performed by means of three consecutive straight lines, which divide the curve of the concentration measured values over the volume measured values into approximated first, second and third sections, wherein the third straight line is used as a limiting straight line for the determination of the serial dead space according to Fowler and by taking the mean volume of the second straight line as the first estimated value for Vds.

[0054] While specific embodiments of the invention have been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. A method for the automatic evaluation and analysis of a capnogram, the method comprising the steps of:
   - recording measured values for an indicator of an expired volume and measured values for an indicator of a carbon dioxide concentration for breathing gas of a test subject;
   - forming a basis for an automatic analysis of the measured values recorded from the measured values for an indicator of the carbon dioxide concentration—concentration measured values—over the measured values for an indicator of the expired volume—volume measured values;
   - performing an automatic approximation of at least part of a curve of the concentration measured values over the volume measured values;
   - using three mutually adjacent straight lines for the approximation; and
   - performing an area determination according to Fowler for a determination of serial dead space (Vds) by means of a third of the three straight lines.
2. A method in accordance with claim 1, wherein an indicator of the quality of a gas exchange in the lungs of the test subject is determined on the basis of the slope of the third straight line.

3. A method in accordance with claim 2, wherein an estimation of the usability of the measured values recorded is performed automatically on the basis of the parameters determined.

4. A method in accordance with claim 3, further comprising automatically evaluating, as a lack of quality of the approximation or lack of usability of the measured values, an actual value being below a preset or presettable threshold value for a difference of an end volume measured value and the volume measured value belonging to a second value pair.

5. A method in accordance with claim 1, wherein the third straight line is determined anew by using a left-hand, first intersection of the straight line with the curve as a new left-hand initial volume value for a repeated fit of the third straight line.

6. A method in accordance with claim 1, wherein the approximation is performed by means of a computer-implemented optimization algorithm including the Levenberg-Marquardt algorithm.

7. A device for the automatic evaluation and analysis of a capnogram, the device comprising:
   means for recording measured values for an indicator of an expired volume and measured values for an indicator of a carbon dioxide concentration for breathing gas of a test subject;
   means for forming a basis for an automatic analysis of the measured values recorded from the measured values for an indicator of the carbon dioxide concentration—concentration measured values—over the measured values for an indicator of the expired volume—volume measured values;
   means for performing an automatic approximation of at least part of a curve of the concentration measured values over the volume measured values using three mutually adjacent straight lines for the approximation and performing an area determination according to Fowler for a determination of serial dead space (Vds) by means of a third of the three straight lines.

8. A device in accordance with claim 7, wherein:
   the means for recording measured values includes a first sensor for recording measured values for the indicator of a volume expired by a test subject and a second sensor for recording measured values for the indicator of a carbon dioxide concentration in the expired volume or with a communicative connection with such sensors and a memory;
   the means for forming a basis for an automatic analysis and the means for performing an automatic approximation includes a processing unit;
   measured values of the sensors are received and stored in a data storage area formed in the memory during the operation of the device;
   a program memory area is formed in the memory; and
   a control program is stored in the program memory with program coding instructions for implementing the automatic analysis and the automatic approximation.

9. A control program with program code instructions executable by a computer or a processing unit for implementing a method comprising the steps of:
   recording measured values for an indicator of an expired volume and measured values for an indicator of a carbon dioxide concentration for breathing gas of a test subject;
   forming a basis for an automatic analysis of the measured values recorded from the measured values for an indicator of the carbon dioxide concentration—concentration measured values—over the measured values for an indicator of the expired volume—volume measured values;
   performing an automatic approximation of at least part of a curve of the concentration measured values over the volume measured values using three mutually adjacent straight lines for the approximation and performing an area determination according to Fowler for a determination of serial dead space (Vds) by means of the third straight line.

10. A control program in accordance with claim 9, wherein an indicator of the quality of a gas exchange in the lungs of the test subject is determined on the basis of the slope of the third straight line.

11. A control program in accordance with claim 10, wherein an estimation of the usability of the measured values recorded is performed automatically on the basis of the parameters determined.

12. A control program in accordance with claim 11, further comprising automatically evaluating, as a lack of quality of the approximation or lack of usability of the measured values, an actual value being below a preset or presettable threshold value for a difference of an end volume measured value and the volume measured value belonging to a second value pair.

13. A control program in accordance with claim 9, wherein the third straight line is determined anew by using a left-hand, first intersection of the straight line with the curve as a new left-hand initial volume value for a repeated fit of the third straight line.

14. A control program in accordance with claim 9, wherein the approximation is performed by means of a computer-implemented optimization algorithm including the Levenberg-Marquardt algorithm.

15. A control program in accordance with claim 9, wherein the control program is provided on a storage medium which is executed by a computer or a processing unit of a device comprising:
   means for recording measured values for an indicator of an expired volume and measured values for an indicator of a carbon dioxide concentration for breathing gas of a test subject;
   means for forming a basis for an automatic analysis of the measured values recorded from the measured values for an indicator of the carbon dioxide concentration—concentration measured values—over the measured values for an indicator of the expired volume—volume measured values;
   means for performing an automatic approximation of at least part of a curve of the concentration measured values over the volume measured values using three mutually adjacent straight lines for the approximation and performing an area determination according to Fowler for a determination of serial dead space (Vds) by means of a third of the three straight lines.

16. A control program in accordance with claim 15, wherein:
   the means for recording measured values includes a first sensor for recording measured values for the indicator of
a volume expired by a test subject and a second sensor for recording measured values for the indicator of a carbon dioxide concentration in the expired volume or with a communicative connection with such sensors and a memory; the means for forming a basis for an automatic analysis and the means for performing an automatic approximation includes the computer or the processing unit; measured values of the sensors are received and stored in a data storage area formed in the memory during the operation of the device; a program memory area is formed in the memory; and the control program is stored in the program memory as the storage medium or is transferred to the program memory from the storage medium.

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